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This is the final report for Contract F44620-75-C-0049 and outlines the accomplishments of the past two years. The near field array operated satisfactorily throughout the contract period but no large earthquakes occurred near the array. A detailed study of seismicity in the Stone Canyon-Bear Valley region of the San Andreas fault suggests a rather regular recurrence time of 11 years for large earthquakes. The body wave-surface wave discriminant continues to be effective for NTS data in the small to medium magnitude range.

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TABLE OF CONTENTS

I Report Summary

This is the final report for Contract F44620-75-C-0049 and outlines the accomplishments of the past two years.

Most of the results of the past two years have been incorporated into 7 published papers and 3 PhD theses. Thus this report only summarizes some of the more important results contained in these publications which are listed in part VII.

The near field array operated satisfactorily throughout the contract period and was removed from the field in January, 1977. During the contract period there were no earthquakes within the array which were large enough to yield the type of data for which the experiment was designed.

A detailed study of historical and current seismicity in the Stone Canyon-Bear Valley region of the San Andreas fault suggests a rather regular recurrence time of 11 years for large earthquakes. The effect of clustering of earthquakes in both time and space has been investigated in a number of studies. The effect of lateral refraction upon fault plane solutions has also been investigated.

Studies of the body wave-surface wave discriminant at near and regional distances and in the small to medium magnitude range have continued with NTS data. The discriminant continues to be effective at small magnitudes, but it appears that no satisfactory explanation of the reasons for its effectiveness is yet available.

Developments of methods of using synthetic seismograms to investigate source mechanisms of earthquakes and explosions has continued. Extensions have been made in the areas of incorporating more complicated source models, more complicated velocity models, and more systematic inversion procedures.

II Introduction

This is the final report of Contract F44620-75-C-0049. This contract was originally funded for the period 01 December 1974 to 30 November 1975. Its primary purpose was to carry on and complete the work started under Grant AFOSR-72-2392. A complete description of the history of the near-field project and the near-field accelerometer array which was developed as part of the University of California's participation in the project can be found in the final report of this earlier grant (McEvilly and Johnson, Final Report, Near Field Accelerometer Array, Grant No. AFOSR-72-2392, 41 pages, 15 May 1975).

In the fall of 1975 it became apparent that the accelerometer array could be left in the field for an additional year with few additional costs. Thus a nine month no-cost extension of the contract was requested and granted. This allowed for an additional period of data recording and also provided an opportunity to complete more analyses of existing data.

The accelerometer array was actually operated until the field batteries began to fail which was in January, 1977. The array has now been removed from the field.

III Operation of the Near-Field Array

The near-field array operated in a satisfactory manner throughout the grant period. Only a couple of changes were made in the array during this time.

At the end of June, 1975, the USGS downgraded their utilization and support of the Stone Canyon Observatory. This affected the operation of the near-field array because the USGS had provided assistance in changing magnetic tapes. At this time, in order to simplify and improve the operation of the array, it was decided to switch the manner of recording the near-field array data from FM recording of the data on individual tracks of four tape transports to direct recording of multiplexed data on a single tape transport. This change has been successful and has resulted in a substantial improvement in the data quality and equipment reliability.

The second change in the array was the addition of a high-gain vertical seismometer to each of the near-field stations. This was done in order to obtain better control over the locations of small earthquakes in the Stone Canyon-Bear Valley region.

IV Studies of Seismicity

Table 1 lists the location parameters of all earthquakes with magnitudes greater than or equal to 2.0 which occurred in and about the Stone Canyon-Bear Valley region during the contract period. Of the 90 events listed in this table, only 6 have magnitudes greater that 3.0 and none of these were close enough or large enough to provide high-quality data from the accelerometer array.

The responsibility of closely monitoring the seismicity in the Stone Canyon-Bear Valley region which the University of California has fulfilled throughout the tenure of the near-field project has led to a comprehensive study of the seismicity in this part of California (McNally, 1976). Data from the 40 year period between 1936 and 1975 were analyzed. Both the uniform station method and the master event method were used to achieve a homogeneous data set. Statistical methods depending upon the properties of the Poisson process were used to identify and remove clusters of earthquakes from the data set. One interesting result which emerged from this analysis was that the larger earthquakes ($M_L \geq 4.9$) in this region have occurred at rather regular 11 year intervals. There is also a suggestion in the data that the degree of clustering may forecast the size of an impending larger earthquake.

This same study by McNally also included a detailed investigation of the faulting mechanism along a section of the San Andreas fault. Fault plane solutions for over 400 earthquakes were computed. The inconsistent first motions fell into a well-defined pattern which can be interpreted as due to lateral refraction of P waves by the fault-plane velocity discontinuity. The angle of apparent refraction is variable along the fault plane, and it may be possible that this type of results

TABLE 1. Stone Canyon-Bear Valley Earthquakes with $M_L > 2$.

Date	Origin Time	Latitude	Longitude	Depth	Magnitude
12 01 74	19 26 13.07	36 39.3	121 16.9	5.36	2.3
12 05 74	11 09 38.02	36 39.0	121 19.9	0.92	2.1
12 01 74	09 10 23.66	36 31.4	121 06.6	9.43	2.3
01 10 75	15 04 36.43	36 45.3	121 20.3	8.84	2.0
02 15 75	01 50 36.12	36 34.3	121 01.3	11.88	2.0
02 19 75	02 01 21.20	36 43.4	121 23.9	3.77	2.0
02 20 75	05 15 03.00	36 36.0	121 12.8	7.17	2.5
02 23 75	17 24 16.81	36 34.3	121 10.3	4.96	2.7
03 06 75	17 08 24.23	36 36.2	121 13.0	8.86	2.0
03 06 75	22 43 41.00	36 35.0	121 11.5	0.93	2.3
03 26 75	20 13 11.92	36 38.9	121 16.4	3.83	3.1
04 24 75	05 23 37.61	36 31.2	121 06.9	6.45	2.0
05 07 75	02 24 04.79	36 33.5	121 09.0	5.44	2.0
05 11 75	21 06 11.99	36 34.3	121 08.3	6.88	2.0
05 16 75	06 05 55.97	36 36.4	121 05.9	11.44	2.3
05 18 75	03 40 15.23	36 29.5	121 04.2	9.81	2.3
05 23 75	05 16 09.44	36 40.0	121 18.0	2.28	2.5
05 25 75	20 39 43.52	36 34.1	121 10.2	3.21	2.3
06 03 75	17 54 20.89	36 34.6	121 10.9	3.18	2.3
06 14 75	12 56 18.71	36 40.8	121 19.3	3.75	3.0
06 14 75	15 24 17.72	36 41.0	121 19.0	2.98	2.0
06 14 75	16 07 35.04	36 41.0	121 19.1	2.28	2.0
06 16 75	10 05 27.48	36 40.5	121 18.3	2.53	2.1
06 25 75	18 26 22.03	36 32.6	121 06.8	6.28	2.3
07 04 75	19 32 04.24	36 34.6	121 02.7	8.48	2.7
07 18 75	21 40 36.68	36 36.0	121 12.8	4.39	2.0
08 11 75	11 03 31.11	36 34.4	121 04.7	11.06	2.5
08 15 75	08 56 34.68	36 35.1	121 07.6	11.61	2.0
08 21 75	11 00 54.22	36 32.3	121 07.4	3.58	2.4
08 27 75	09 53 42.63	36 38.9	121 16.5	4.12	2.5
08 31 75	05 52 39.46	36 33.0	121 08.8	7.23	2.8
09 06 75	05 17 01.25	36 35.1	121 07.7	8.43	2.7
09 07 75	21 00 11.19	36 38.8	121 16.1	5.51	2.2
09 08 75	00 20 04.59	36 35.2	121 07.5	10.12	2.0
09 20 75	00 51 04.82	36 33.1	121 06.3	8.36	2.6
09 30 75	03 05 54.49	36 44.1	121 25.4	6.13	2.0
10 04 75	04 25 33.58	36 35.1	121 11.3	6.84	2.1
10 12 75	20 52 42.10	36 28.7	121 04.0	6.61	2.5
11 05 75	03 28 50.32	36 39.6	121 17.6	5.82	2.8
11 09 75	14 17 17.65	36 34.3	121 08.7	8.23	2.3
11 29 75	02 38 33.92	36 42.1	121 20.9	0.23	2.9
12 03 75	10 29 39.09	36 37.5	121 14.34	7.52	2.0
12 09 75	08 35 32.08	36 32.2	121 07.8	7.74	2.9
12 21 75	03 24 51.82	36 35.5	121 04.1	5.34	2.4
12 26 75	04 57 30.37	36 37.5	121 13.5	11.24	2.1

01 15 76	12 20 07.04	36 34.8	121 11.4	2.65	2.4
03 16 76	12 29 58.06	36 30.4	121 04.9	7.49	2.0
04 09 76	18 48 12.12	36 35.5	121 11.8	7.03	2.4
04 14 76	20 44 06.44	36 34.4	121 10.5	5.67	2.9
04 19 75	11 09 10.45	36 34.4	121 09.7	8.15	2.1
04 19 76	17 05 45.21	36 37.7	121 14.6	7.59	2.1
04 23 76	16 35 08.15	36 39.1	121 16.1	11.01	2.0
06 02 76	16 34 48.27	36 40.8	121 17.4	4.66	2.7
06 04 76	05 50 11.37	36 40.6	121 18.6	2.85	2.5
06 17 76	06 29 49.39	36 40.1	121 18.1	1.95	2.2
06 20 76	11 36 35.90	36 29.7	121 04.7	10.58	2.4
06 26 76	12 09 25.93	36 45.9	121 23.2	8.26	2.2
07 06 76	18 48 10.59	36 35.7	121 12.0	8.56	2.3
07 20 76	07 25 48.14	36 30.3	121 04.9	7.64	2.0
07 26 76	13 50 05.00	36 22.8	121 10.0	6.17	2.3
07 26 76	14 00 01.66	36 33.1	121 10.1	6.03	2.0
08 12 76	20 49 50.34	36 34.4	121 10.5	5.03	2.5
08 29 76	14 16 11.16	36 30.3	121 06.0	4.45	2.0
09 03 76	17 12 26.35	36 43.3	121 22.4	3.20	2.7
09 03 76	19 58 49.97	36 43.2	121 22.7	3.42	3.5
09 07 76	11 46 20.36	36 33.5	121 09.0	9.97	2.6
09 11 76	09 28 57.33	36 37.7	121 16.3	2.96	2.4
09 26 76	07 46 48.2	36 38.0	121 15.4	4.60	2.3
10 02 76	09 18 28.58	36 41.3	121 19.7	2.25	2.3
10 08 76	09 53 26.44	36 29.1	121 03.8	10.76	2.6
10 09 76	18 58 04.69	36 42.2	121 20.9	3.23	2.0
10 13 76	22 36 59.53	36 35.6	121 11.6	5.15	2.0
10 28 76	05 30 26.91	36 32.7	121 07.7	5.07	2.0
11 04 76	00 32 23.29	36 33.8	121 09.2	10.61	2.8
11 10 76	08 22 10.05	36 42.2	121 19.7	5.32	2.2
11 24 76	16 34 38.96	36 30.3	121 05.2	6.70	2.3
11 24 76	22 27 42.13	36 35.5	121 11.8	4.07	2.3
11 25 76	15 58 25.72	36 38.5	121 16.0	5.98	3.5
11 25 76	16 44 56.05	36 38.5	121 16.0	7.35	2.4
11 26 76	18 52 39.45	36 35.4	121 11.7	4.67	2.5
12 02 76	07 24 53.11	36 37.5	121 14.5	6.12	3.3
12 04 76	14 18 19.18	36 37.3	121 14.4	5.72	2.0
12 13 76	00 05 49.71	36 37.1	121 14.3	5.69	2.3
12 28 76	00 01 16.19	36 31.7	121 08.2	9.76	2.1
01 06 77	09 28 01.34	36 38.5	121 16.1	8.42	3.0
01 07 77	00 53 35.77	36 38.2	121 15.2	4.96	2.2
01 09 77	00 20 33.44	36 40.8	121 09.2	9.18	2.1
01 10 77	10 07 10.21	36 41.1	121 17.4	3.31	2.1
01 22 77	12 18 26.57	36 36.6	121 12.8	8.37	2.5
01 28 77	10 40 43.39	36 35.3	121 12.0	6.86	2.2

can provide information about conditions near the source of large earthquakes. This interesting possibility is receiving more study.

The matter of clustering was also the subject of a study by Udias and Rice (1975). Analysis of over 4700 microearthquakes occurring in a four-year period in a region of radius 25 km centered on the San Andreas fault showed a strong departure from the distribution expected for a Poisson process. The average cluster size was estimated to be about 2.

Another study (Udias, 1976) investigated the distribution of magnitudes within aftershock sequences in this same region. It was discovered that a 1971 series of earthquakes in Bear Valley had a b value of only 0.4 whereas two series occurring 15 km to the north in 1968 and 1970 had more normal b values of 1.1 and 0.9, respectively. This marked difference may indicate significant differences in the material properties or the stress regime in these two near-by regions along the San Andreas fault.

V Studies of Source Properties

Investigation of small and medium magnitude events at the Nevada Test Site continued with the study of Peppin and McEvilly (1974). Data from 56 events at NTS recorded by the broadband seismic array of the University of California Lawrence Livermore Laboratory were used. It was found that natural earthquakes, explosion collapses, and explosion aftershocks all can be distinguished from explosions on the basis of a body wave-surface wave discriminant. The data extend down to magnitudes (M_L) of 3.5. On the basis of this study it is concluded that the body wave-surface wave discriminant cannot be explained by appealing to differences in source dimension, focal depth, or focal mechanism.

Analyses have also been completed of a set of seismograms recorded within 30 km of the explosions JORUM, PIPKIN, and HANDLEY and another set recorded in the distance range or 200-300 km from these same explosions plus other explosions and earthquakes at NTS. One of the conclusions of this study is that earthquakes and explosions of similar magnitude cannot be distinguished from each other on the basis of the corner frequencies of their source spectra.

The data and methods of analysis for the two studies mentioned above are given in more detail in the thesis of Peppin (1974).

VI Studies Using the Synthetic Seismogram Approach

One of the more important results of the near-field project has been the development of the capability to interpret seismograms by fitting them with synthetic seismograms. An advantage of this approach is that it contains the potential for separating source effects from propagation effects.

The study of Litehiser (1976) was an attempt to explain the strong-motion accelerometer records generated at Pacoima Dam during the San Fernando earthquake of 9 February 1971 in terms of a propagating dislocation source. By using synthetic seismograms calculated for a two-dimensional halfspace model, it was shown that the entire 10 sec of significant ground motion could be reasonably well explained by a dislocation of 1 to 2 meters having a rise time of 0.25 sec propagating upward toward the surface with a velocity of approximately 2.3 km/sec over a hinged fault surface.

In another study (Helmberger and Johnson, 1977), synthetic seismograms were used to interpret broadband seismograms recorded from three earthquakes in the Stone Canyon-Bear Valley region of the San Andreas fault. In order to explain distinctively dissimilar seismograms recorded on opposite sides of the fault it was necessary to use different crustal structures for the two sides of the fault. The arguement is made that propagation effects are dominant in determining the character of these particular seismograms.

The problem of using synthetic seismograms to estimate source parameters has been posed as an inverse problem by Stump (1976). Representing the

source in terms of a second order moment tensor and with reasonable assumptions, it is shown that the problem can be put in linear algebraic form in both the time domain and frequency domain. The method has been tested extensively with synthetic data and appears to have wide applicability. It is now being applied to observational data.

VII Papers

The following papers report work which was completed during the near field project. Those marked with an * were completed during the present contract period.

* Helmberger, D. V., and L. R. Johnson; Source parameters of moderate size earthquakes and the importance of receiver crustal structure in interpreting observations of local earthquakes, Bull. Seism. Soc. Am., (in press), 1977.

Johnson, L. R.; Green's function for Lamb's problem, Geophys. J. R. Astr. Soc., 37, 99-131, 1974.

Johnson, L. R., A. Mazzella, T. V. McEvilly, and H. F. Morrison; A search for premonitory changes in seismic velocities and deep resistivity associated with central California earthquakes, paper presented at Symposium on Earthquake Forerunners Searching, Tashkent, USSR, 27 May - 3 June, 1974.

Johnson, L. R., and T. V. McEvilly; Near-field observations and source parameters of central California earthquakes, Bull. Seism. Soc. Am., 64, 1855-1886, 1974.

Kurita, T.; Attenuation of shear waves along the San Andreas fault zone in central California, Bull. Seism. Soc. Am., 65, 277-292, 1975.

* Kurita, T.; Source parameters of central California earthquakes on February 24 and September 4, 1972, Phys. Earth Planet. Inter., 13, 18-36, 1976.

Litehiser, J., Near-field accelerations from a propagating dislocation, paper presented at the Fall Annual Meeting of the American Geophysical Union, San Francisco, December 4-7, 1972.

Litehiser, J.; Near-field accelerations from a propagating dislocation, San Fernando earthquake, paper presented at the Annual Meeting of the American Geophysical Union, Washington, D.C., April 8-12, 1974.

* Litehiser, J. J.; Near-field seismograms from a two-dimensional propagating dislocation, PhD Thesis, University of California, Berkeley, 1976.

McNally, K; The process of earthquake occurrence on an active fault segment, paper presented at the Annual Meeting of the Seismological Society of America, Las Vegas, March 29-31, 1974.

* McNally, K, and T. V. McEvilly; Faulting details from first motion studies in central California, paper presented at Fall Annual Meeting of the American Geophysical Union, San Francisco, December 12-17, 1974.

* McNally, K.; Spatial, temporal, and mechanistic character in earhtquake occurrence: a segment of the San Andreas fault in central California, PhD Thesis, University of California, Berkeley, 1976.

Peppin, W., G. Simila, D. Gehant, and T. V. McEvilly; Detailed seismicity of the Cape Mendocino area, paper presented at Fall Annual Meeting of the American Geophysical Union, San Francisco, December 4-7, 1972.

* Peppin, W. A.; The cause of the body wave-surface wave discriminant between earthquakes and underground explosions at near-regional distances, PhD Thesis, University of California, Berkeley, 1974.

* Peppin, W. A., and T. V. McEvilly; Discrimination among small magnitude events on Nevada Test Site, Geophys. J. R. Astr. Soc., 37, 227-244, 1974.

* Peppin, W. A.; P-wave spectra of Nevad Test Site events at near and very near distances: implications for a near-regional body wave-surface wave discriminant, Bull. Seism. Soc. Am., 66, 803-825, 1976.

Savage, W. U., and K. McNally; Moderate earthquake seismicity in central California, 1936-1973, paper presented at Annual Meeting of the Seismological Society of America, Las Vegas, March 29-31, 1974.

* Simila, G. W.; Dilatancy and sea level changes, paper presented at Fall Annual Meeting of the American Geophysical Union, San Francisco, December 12-17, 1974.

* Simila, G., W. Peppin, and T. V. McEvilly; Seismotectonics of the Cape Mendocino, California, area, Geol. Soc. Am. Bull., 86, 1399, 1975.

* Stump, B.; P and S corner frequencies observed in the near field and the effect of attenuation, paper presented at the Fall Annual Meeting of the American Geophysical Union, San Francisco, December 12-17, 1974.

* Stump, B.; The determination of source mechanisms by the linear inversion of seismograms, paper presented at the Fall Annual Meeting of the American Geophysical Union, San Francisco, December 6-10, 1976.

* Udias, A., and J. Rice; Statistical analysis of microearthquake activity near San Andreas Geophysical Observatory, Hollister, California, Bull. Seism. Soc. Am., 65, 809-827, 1975.

* Udias, A.; Time and magnitude relations for three microaftershock series near Hollister, California, Bull. Seism. Soc. Am., 67, 173-185, 1977.